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2.	Patent application number *(The Patent Office will fill in this part)*	**9902479.6**
3.	Full name, address and postcode of the or of each applicant *(underline all surnames)*	The University Court of the University of Glasgow University Avenue Glasgow G12 8QQ
	Patents ADP number *(if you know it)*	5646542001
	If the applicant is a corporate body, give the country/state of its incorporation	United Kingdom
4.	Title of the invention	"Waveguide for an Optical Circuit and Method of Fabrication Thereof"
5.	Name of your agent *(if you have one)*	Murgitroyd & Company
	"Address for service" in the United Kingdom to which all correspondence should be sent *(including the postcode)*	373 Scotland Street GLASGOW G5 8QA
	Patents ADP number *(if you know it)*	1198013

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Country	Priority application number *(if you know it)*	Date of filing *(day / month / year)*

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Murgitroyd & Company 4 February 1999

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DUPLICATE

WAVEGUIDE FOR AN OPTICAL CIRCUIT AND METHOD OF FABRICATION THEREOF

FIELD OF THE INVENTION

The present invention relates to a waveguide for an optical circuit, and a method of fabrication thereof.

The method relates in particular to the fabrication of a waveguide for an optical circuit with smoothed waveguide core boundaries. More specifically, the method relates to the fabrication of a rounded, elliptical or circular waveguide core by the isotropic diffusion of dopants in a core layer of a phosphosilicate waveguide wafer, such that the diffused core layer forms the circular waveguide core. This diffusion is thermally promoted either during the deposition of an upper cladding layer or by subsequent thermal processing of the waveguide wafer.

BACKGROUND OF THE INVENTION

The general process of fabricating a glass waveguide for optical circuits comprises forming at least one buffer layer, e.g. a thermal oxide layer, on a silicon wafer substrate. Additional buffer layers and/or at

least one lower cladding layers may then be formed on top of the buffer layer. A core layer composed of a doped silica film is then formed on top of the buffer layer or lower cladding layer.

The core layer is then etched, for example, by reactive ion techniques, to form a square or rectangular waveguide or other suitable cross-sectional profile. The etched core is then embedded by an upper cladding layer.
The core layer refractive index is usually higher than that of the surrounding layers. This concentrates the propagation of light in the core layer.

Planar channel waveguides are usually formed using dry etch methods to produce waveguides with square or rectangular cross-sections. Such angular waveguides have several disadvantages, in particular the geometrical mismatch between the waveguides and optical fibres in an optical circuit. The production of channel waveguides with a circular cross-section is particularly advantageous in that this increases the transmission efficiency between the waveguide and the rest of an optical circuit.

Channel waveguides are also susceptible to scatter loss (Mie scattering) due to imperfections in their sidewalls. This is reduced by smoothing the profile of the waveguide and this provides low propagation loss in the waveguides.

Circular optical waveguides are known in principle (for example, see Sun et al., "Silica-based circular cross-sectioned channel waveguides", IEEE Photonics Technology Letters, 3, p.p. 238-240, 1991). Sun et al., disclose large dimension (~50μm) GeO_2 doped silica

waveguides which are reactive ion etched to form rectangular channel cross-sections. This method involves depositing a lower cladding layer with a reduced amount of Germanium doped silicon on to the wafer substrate prior to the deposition of a core layer. When the wafer is placed in the selective wet etch, the lower cladding layer is etched at a much faster rate to form a pedestal underneath the core region.

According to Sun et al., the waveguide can then be heated above the core softening temperature so that the surface tension of the glass functions to round the waveguide core. Such wet etching techniques are time consuming and moreover, do not offer truly circular cross sections as the core cannot be rounded at the interface between the core layer and the pedestal (i.e., the lower cladding layer lying directly beneath the core).

The current invention in contrast relies on the mobility of dopant ions in a square or rectangular etched core to migrate outwards into both upper and lower cladding layers. This forms waveguides which have substantially smoothed boundary walls, in particular the side walls are smoothed.

Further diffusion rounds the core region, and providing the diffusion is sufficiently isotropic the core region becomes sufficiently rounded to form a circular waveguide. This diffusion is thermally promoted either during the consolidation of the upper cladding layer or during subsequent thermal processing. By selecting the composition of the upper and lower cladding layers, the refractive indexes and consolidation temperatures can be chosen to modify the rate at which the core dopant

ions diffuse into each layer and the elipticity of the resulting waveguide core accordingly adjusted.

SUMMARY OF THE INVENTION

According to a first aspect of the present invention, there is provided a waveguide for an optical circuit comprising:

a substrate;

a doped lower cladding layer;

a doped waveguide core formed on the lower cladding layer; and

a doped upper cladding layer embedding the waveguide core;

wherein the waveguide core includes mobile dopant ions which have diffused into the upper cladding layer and the lower cladding layer to form an ion diffusion region around said waveguide core such that the waveguide core boundary walls are substantially smooth.

According to a second aspect of the present invention, there is provided a method for fabricating a waveguide comprising the steps of:

providing a substrate;

forming a doped lower cladding layer;

forming a doped core layer on the lower cladding layer;

forming a waveguide core from the core layer;

forming a doped upper cladding layer to embed the waveguide core;

wherein mobile ion dopants included in the core layer undergo diffusion into the surrounding upper cladding layer and lower cladding layer to form an ion diffusion region around the waveguide core such that the waveguide core boundary walls are substantially

smooth.

DESCRIPTION OF THE DRAWINGS

Embodiments of the present invention will now be described by way of example only with reference to the accompanying drawings in which:-

Fig. 1 is a cross-sectional diagram of a conventionally rounded waveguide;

Figs. 2A to 2E are a cross-sectional diagrams showing stages in the fabrication of a rounded waveguide according to the present invention;

DETAILED DESCRIPTION OF THE INVENTION

With reference to the drawings, there is described now a waveguide for an optical circuit and a method of fabrication thereof according to the present invention.

A waveguide produced by conventional techniques which can partially round the cross-section of the core layer of a waveguide is shown in Fig.1. This illustrates such a waveguide 1 with a rounded core upper cross-section 2 and flat base 3 supported by a pedestal 4 embedded in a cladding layer 5 as might be formed by the conventional method of *Sun et al*.

The present invention provides a waveguide which does not exhibit the flat base 3 shown in Fig.1. Various stages in the method of fabricating such a waveguide will now be described with reference to Figs. 2A to 2E.

Fig. 2A is a schematic diagram showing the preliminary stages in a method of fabricating a waveguide with an

elliptical or rounded cross-section from a silicon wafer according to a first embodiment of the invention.

In this embodiment, a silicon substrate 6 is covered with a buffer layer 7 comprising thermally oxidised silicon. In alternative embodiments of the invention, the substrate 6 comprises silica and sapphire and the buffer layer 7 further includes at least one Phosphorus oxide and/or Boron oxide. The thickness of the thermally oxidised silicon buffer layer 7 ranges between 0.2 μm and 20 μm.

A lower cladding layer 8, doped with Phosphorus and Boron ions and having a refractive index matched to the buffer layer 7, is then deposited using a Flame Hydrolysis Deposition (FHD) process on to the buffer layer 7, and is consolidated either in an electrical furnace or by using an FHD burner.

By way of example, the FHD process used for deposition of the lower cladding layer 8 can employ the following input feed flow rates for the feed gases:-
Shroud gas 5 litres/min; O_2 4 litres/min;
H_2 2 litres/min; $SiCl_4$ carrier gas 0.15 litres/min;
PCl_3 carrier gas 0.04 litres/min;
BCl_3 carrier gas 0.09 litres/min . The halides are carried, for example, by an N_2 carrier gas, and the shroud gas can, for example, be N_2.

The lower cladding layer 8 formed comprises silica, Phosphorus oxide, and Boron oxide; for example SiO_2-P_2O_5-B_2O_3. In alternative embodiments, the lower cladding layer 8 may contain dopant ions in addition to SiO_2-P_2O_5-B_2O_3. The doping levels for the silica, Phosphorus oxide and Boron oxide in the lower cladding layer 8 are 82 wt% silica, 5 wt% Phosphorus oxide and 13 wt% Boron

oxide. Varying the flow rates of the input gases in the FHD burner results in different doping levels. In other embodiments of the invention, the preferred doping levels range between 75 to 95 wt% silica, 1 to 7 wt% Phosphorus oxide and 4 to 18 wt% Boron oxide, or alternatively range between 80 to 90 wt% silica, 2.5 to 6 wt% Phosphorus oxide, and 7.5 to 14 wt% Boron oxide.

The lower cladding layer 8 is consolidated by fully fusing the layer in an electric furnace at a temperature of 1250°C, which is in a preferred range of temperatures of between 1100°C to 1350°C.

In alternative embodiments, the lower cladding layer 8 is deposited using an FHD process and can be consolidated at different temperatures within a range of temperatures of between 950°C to 1400°C.

In a further alternative, the lower cladding layer 8 is deposited by a Flame Hydrolysis Deposition (FHD) process and partially consolidated at this stage and fully consolidated subsequently.

The thickness of the lower cladding layer 8 deposited is 2 μm but can range between 1 μm and 20 μm.

In alternative embodiments, where no buffer layer is employed, the lower cladding layer 8 can be formed directly on top of the substrate 6.

A core layer 9 comprising Phosphorus oxide and silica, for example, P_2O_5-SiO_2 is then formed on the lower cladding layer 8. The refractive index of the core layer 9 differs from that of the lower cladding layer 8 by 0.75%, and may differ by a value within the range of 0.05 % to 2 %.

By way of example, the FHD process used for deposition of the core layer 9 can employ the following input feed flow rates for the feed gases:-
Shroud gas 5 litres/min; O_2 6 litres/min;
H_2 4 litres/min; $SiCl_4$ carrier gas 0.15 litres/min;
PCl_3 carrier gas 0.018 litres/min. The halides are carried, for example, by an N_2 carrier gas, and the shroud gas can, for example, be N_2.

The core layer 9 is consolidated by fully fusing the layer in an electric furnace at a temperature of 1200°C, which is in a preferred range of temperatures of between 1100°C to 1385°C.

In alternative embodiments, the core layer 9 is deposited using an FHD process and can be consolidated at different temperatures within a range of temperatures of between 950°C to 1400°C.

In a further alternative, the core layer 9 is partially consolidated at this stage and consolidated subsequently.

The dopant levels for the core layer 9 are 80 wt% silica and 20 wt% Phosphorus oxide in the preferred embodiment. In alternative embodiments, the input gases into the FHD burner are varied to give core dopant levels between 75 to 95 wt% silica and 5 to 25 wt% Phosphorus oxide respectively. The thickness of the core layer deposited is 6 μm but can range between 2 μm and 60 μm.

The core layer mobile ion dopants include Phosphorus ions but could, for example, include Fluorine ions. In alternative embodiments, the core layer 9 is doped Phosphorus and co-doped with ions with desired

properties to effect reduction of the sintering temperature and/or to effect increase of the core layer refractive index. The co-dopants may be selected from the group comprising Aluminium, Boron, Germanium, Tin and/or Titanium. For example, co-doping with Germanium reduces the sintering temperature and raises the silica based core layer 9 refractive index so that the refractive index is higher than the refractive index of the lower cladding layer 8 on top of which the core layer 9 is deposited.

The lower cladding layer 8 is susceptible to interdiffusion from the dopant ions from the core layer 9. In contrast, the buffer layer 7 acts as a barrier against interdiffusion.

Fig. 2B shows the subsequent stage in the method of fabricating an optical waveguide in which the core layer 9 is redefined by removing regions 10 by a reactive ion etching (RIE) technique to form a square waveguide core 11. In general, a square or rectangular waveguide core 11 whose dimensions range from 2 μm to 60 μm will be suitable in the method of fabricating an optical waveguide, preferred dimensions being such as to give a waveguide core 11 of 6μm x 6 μm.

Alternative techniques for forming a square or rectangular waveguide core 11 can be used, or a combination of techniques. For example, dry etching techniques (e.g. reactive ion etching, ion milling, and/or plasma etching processes), a photolithographic technique, and/or a mechanical sawing process may be used.

Subsequently, the waveguide core 11 is embedded by an upper cladding layer 12 (as shown in Fig. 2C)

comprising Phosphorus oxide, Boron oxide and silica. Preferably, the upper cladding layer 12 has the same composition as the lower cladding layer 8 (P_2O_5-B_2O_3-SiO_2) and the same refractive index. Alternatively, the upper cladding layer 12 can have a different composition from the lower cladding layer 8 but can have substantially the same refractive index. The upper cladding layer 12 can be deposited using the same input gas flow parameters into the FHD apparatus as for the lower cladding layer 8.

The upper cladding layer 12 is then consolidated in a furnace and by adjusting the duration and temperature of the heat treatment the amount of diffusion of the dopant ions in the waveguide core 11 can be adjusted.

The upper cladding layer 12 is consolidated by fully fusing the upper cladding layer 12 in an electric furnace for about 90 minutes at a minimum temperature of 1050°C and preferably at a temperature of 1200°C, which is in a preferred range of temperatures of between 1100°C to 1250°C.

The consolidation temperature of the upper cladding layer 12 is a minimum of 1050 °C for the given co-dopant levels. In alternative embodiments, for other co-dopant levels, the upper cladding layer 12 is deposited using an FHD process and can be consolidated at different temperatures within a range of temperatures of between 950°C to 1250°C. By suitably varying the co-dopant levels in the upper cladding layer 12 the consolidation temperature can be reduced to below 950°C.

Fig. 2D shows how the consolidation temperature of the upper cladding layer 12 promotes diffusion of the

mobile core dopant ions into the upper cladding layer 12 and lower cladding layer 8. The composition of the upper and lower cladding layers 8 and 12 gives a diffusion length of 2μm when the consolidation temperature of the core layer 9 and upper cladding layer 12 is 1200°C. More typically, the diffusion length is between the range of 0.1 μm to 3 μm for the preferred ranges of consolidation temperatures.

The upper cladding layer 12 is consolidated at a temperature which is the same as or greater than a temperature which promotes efficient diffusion of the waveguide core 11.

The ion dopant concentration in the lower cladding layer 8 and upper cladding layer 12 is chosen so that the waveguide core 11 has a higher concentration of dopant ions to promote diffusion of the waveguide core 11 dopant ions into the lower cladding layer 8 and upper cladding layer 12. In the preferred embodiment, the diffusion of the mobile ion dopants in the waveguide core 11 into the surrounding cladding layers 8 and 12 occurs during consolidation of the upper cladding layer 12, during which the core boundaries of the waveguide core 11 are rounded and a waveguide 13 is formed which is circular in cross-section.

In an alternative embodiment, subsequent thermal processing after the consolidation of the upper cladding layer 12 promotes diffusion of the mobile ion dopants in the waveguide core 11 into the surrounding cladding layers 8 and 12.

Fig. 2E shows the resulting rounded waveguide 13.

In other embodiments of the invention, a silica based

waveguide core 11 may be doped with Phosphorus and Germanium to raise the refractive index of the waveguide core 11 and to reduce the consolidation temperature of the waveguide core 11. Alternative techniques may be used to redefine the waveguide core 11 from the core layer 9; e.g. photolithographic, plasma etching processes, ion milling process, mechanical sawing process, and RIE processes.

In other embodiments, the waveguide core 11 may comprise more than one core layer 9. Such core layers 9 could be chosen to have substantially the same refractive index but differ in material composition.

Other embodiments of the invention may require additional interdiffusion upper cladding layers 12 and lower cladding layers 8 to be deposited above and/or below the waveguide core 11. To promote isotropic diffusion, the lower cladding layers 8 may have the same composition and/or the same refractive index as that of the upper cladding layers 12. The isotropy of the refractive index surrounding the waveguide core 11 promotes circular diffusion and a circular waveguide core 13 results.

In other embodiments, a Chemical Vapour Deposition (CVD) method, or a Plasma Enhanced Chemical Vapour Deposition (PECVD) method, or a combination of these methods can be used to form the cladding layers 8 and 12 and the core layer 9. Subsequent thermal processing of the waveguide promotes diffusion of ion dopants from the waveguide core 11 into the surrounding upper cladding and lower cladding layers 8 and 12.

In other embodiments, the lower cladding layer 8 may be only partially consolidated before the core layer 9 is

deposited thereon and fully consolidated when the core layer 9 is consolidated. Furthermore, the waveguide core 11 may only be partially consolidated when the upper cladding layer 12 is formed thereon and may be fully consolidated when the upper cladding layer 12 is consolidated. Also, the FHD burner can be used for fusing by passing the burner over the waveguide to fuse the lower cladding and upper cladding layers 8 and 12 and to fuse the core layer 9.

While several embodiments of the present invention have been described and illustrated, it will be apparent to those skilled in the art once given this disclosure that various modifications, changes, improvements and variations may be made without departing from the spirit or scope of this invention.

Claims:

1 A waveguide for an optical circuit comprising:

a substrate;

a doped lower cladding layer;

a doped waveguide core formed on the lower cladding layer; and

a doped upper cladding layer embedding the waveguide core;

wherein the waveguide core includes mobile dopant ions which have diffused into the upper cladding layer and the lower cladding layer to form an ion diffusion region around said waveguide core such that the waveguide core boundary walls are substantially smooth.

2. A waveguide as claimed in Claim 1, and further including a buffer layer formed on the substrate and wherein the lower cladding layer is formed on the buffer layer.

3. A waveguide as claimed in either preceding claim, wherein the substrate comprises silicon and/or silica and/or sapphire.

4. A waveguide as claimed in Claim 3, wherein said buffer layer includes a thermally oxidised layer of the substrate.

5. A waveguide as claimed in any preceding claim, wherein the buffer layer comprises doped silica.

6. A waveguide as claimed in any preceding claim, wherein the thickness of the buffer layer is in the range 0.2μm to 20μm.

7. A waveguide as claimed in any preceding claim,

wherein the lower cladding layer comprises doped silica.

8. A waveguide as claimed in any preceding claim, wherein the lower cladding layer includes at least one Phosphorus oxide and/or at least one Boron oxide.

9. A waveguide as claimed in Claim 8, wherein the lower cladding layer includes at least one Phosphorus oxide and at least one Boron oxide and wherein the Phosphorus oxide to Boron oxide ratio is such that the lower cladding layer refractive index is substantially equal to the refractive index of the buffer layer.

10. A waveguide as claimed in any preceding claim, wherein the lower cladding layer includes doped silica, at least one Phosphorus oxide and at least one Boron oxide and wherein the silica:Phosphorus oxide:Boron oxide ratio is in the range of 75 to 95 wt% silica:1 to 7 wt% Phosphorus oxide:4 to 18 wt% Boron oxide.

11. A waveguide as claimed in Claim 10, wherein the lower cladding layer has a silica:Phosphorus oxide:Boron oxide ratio in the range of 80 to 90 wt% silica:2.5 to 6 wt% Phosphorus oxide:7.5 to 14 wt% Boron oxide.

12. A waveguide as claimed in Claim 11, wherein the lower cladding layer has a silica; to Phosphorus oxide; to Boron oxide ratio of 82 wt% silica; to 5 wt% Phosphorus oxide; to 13 wt% Boron oxide.

13. A waveguide as claimed in any preceding claim, wherein the thickness of the lower cladding layer is $1\mu m$ to $20\mu m$.

14. A waveguide as claimed in any preceding claim, wherein the waveguide core comprises doped silica.

15. A waveguide as claimed in any preceding claim, wherein said mobile dopant ions of the waveguide core include Phosphorus and/or Fluorine and/or compounds of these elements.

16. A waveguide as claimed in any preceding claim, wherein dopant ions of the waveguide core include Phosphorus and/or Fluorine and/or Aluminium and/or Boron and/or Germanium and/or Tin and/or Titanium and/or compounds of these elements.

17. A waveguide as claimed in any preceding claim, wherein the waveguide core includes Phosphorus oxide and/or Boron oxide.

18. A waveguide as claimed in Claim 17, wherein the waveguide core comprises P_2O_5-SiO_2.

19. A waveguide as claimed in any preceding claim, wherein the refractive index of the waveguide core differs from that of the lower cladding layer by at least 0.05%.

20. A waveguide as claimed in any preceding claim, wherein the waveguide core includes silica, and at least one Phosphorus oxide and wherein the silica to Phosphorus oxide ratio is in the range of 75 to 95 wt% silica to 5 to 25 wt% Phosphorus oxide.

21. A waveguide as claimed in Claim 20, wherein the waveguide core has a silica to Phosphorus oxide ratio of 80 wt% silica to 20 wt% Phosphorus oxide.

22. A waveguide as claimed in any preceding claim, wherein the thickness of the waveguide core is in the range 2μm to 60μm.

23. A waveguide as claimed in Claim 22, wherein the thickness of the waveguide core is 6μm.

24. A waveguide as claimed in any preceding claim, wherein the lower cladding layer and the upper cladding layer refractive indices are substantially equal.

25. A waveguide as claimed in any preceding claim, wherein the lower cladding layer and the upper cladding layer comprise the same material.

26. A waveguide as claimed in any preceding claim, wherein the waveguide core has a mobile ion dopant concentration higher than the mobile ion dopant concentration of the lower cladding layer or the upper cladding layer.

27. A waveguide as claimed in any preceding claim, wherein the ion diffusion region is isotropic with respect to the waveguide core.

28. A waveguide as claimed in any preceding claim, wherein the ion diffusion region surrounding the waveguide core forms a substantially rounded waveguide core.

29. A waveguide as claimed in Claim 26 wherein the rounded waveguide core is elliptical or circular in cross-section.

30. A method of fabricating a waveguide comprising the steps of:

providing a substrate; .

forming a doped lower cladding layer;

forming a doped core layer on the lower cladding layer;

forming a waveguide core from the core layer;

forming a doped upper cladding layer to embed the waveguide core;

wherein mobile ion dopants included in the core layer undergo diffusion into the surrounding upper cladding layer and lower cladding layer to form an ion diffusion region around the waveguide core such that the waveguide core boundary walls are substantially smooth.

31. A method as claimed in Claim 30, and including the step of forming a buffer layer on the substrate.

32. A method as claimed in Claim 31, wherein the lower cladding layer is formed on said buffer layer.

33. A method as claimed in any of Claims 30 to 32, wherein the steps of forming each of the lower cladding layer, the core layer and the upper cladding layer comprise the steps of:

depositing each layer; and

at least partially consolidating each layer.

34. A method as claimed in Claim 33, wherein any of the lower cladding layer, the core layer and the upper cladding layer partially consolidated after deposition is fully consolidated with the full consolidation of any other of the lower cladding layer, the core layer or the upper cladding layer.

35. A method as claimed in any of Claims 30 to 34, wherein the diffusion of mobile ion dopants in the core layer occurs during the consolidation of the lower cladding layer and/or the upper cladding layer.

36. A method as claimed in any of Claims 30 to 35 further comprising at least one thermal processing step after the formation of the upper cladding layer, wherein during said thermal processing of the waveguide the mobile ion dopants in the core layer undergo diffusion into the surrounding layers.

37. A method as claimed in any of Claims 30 to 36, wherein the substrate comprises silicon and/or silica and/or sapphire.

38. A method as claimed in any of Claims 30 to 37, wherein the buffer layer includes a thermally oxidised layer of the substrate.

39. A method as claimed in any of Claims 30 to 38, wherein the buffer layer comprises doped silica.

40. A method as claimed in any of Claims 30 to 39, wherein the thickness of the buffer layer formed is in the range of 0.2μm to 20μm.

41. A method as claimed in any preceding claim, wherein the lower cladding layer comprises doped silica.

42. A method as claimed in any preceding claim, wherein the lower cladding layer includes at least one Phosphorus oxide and/or Boron oxide.

43. A method as claimed in Claim 42, wherein the lower

cladding layer includes at least one Phosphorus oxide and at least one Boron oxide and wherein the Phosphorus oxide to Boron oxide ratio is such that the lower cladding layer refractive index is substantially equal to the refractive index of the buffer layer.

44. A method as claimed in any of Claims 30 to 43, wherein the lower cladding layer includes silica, at least one Phosphorus oxide and at least one Boron oxide and wherein the silica; to Phosphorus oxide; to Boron oxide ratio in the range of 75 to 95 wt% silica; to 1 to 7 wt% Phosphorus oxide; to 4 to 18 wt% Boron oxide.

45. A method as claimed in Claim 44, wherein the lower cladding layer has a silica; to Phosphorus oxide; to Boron oxide ratio in the range of 80 to 90 wt% silica; to 2.5 to 6 wt% Phosphorus oxide; to 7.5 to 14 wt% Boron oxide.

46. A method as claimed in Claim 45, wherein the lower cladding layer has a silica; to Phosphorus oxide; to Boron oxide ratio of 82 wt% silica; to 5 wt% Phosphorus oxide; to 13 wt% Boron oxide.

47. A method as claimed in any of Claims 30 to 46, wherein the thickness of the lower cladding layer is $1\mu m$ to $20\mu m$.

48. A method as claimed in any of Claims 30 to 47, wherein the core layer comprises doped silica.

49. A method as claimed in any of Claims 30 to 48, wherein said mobile dopant ions of the waveguide core include Phosphorus and/or Fluorine and/or compounds of these elements.

50. A method as claimed in any of Claims 30 to 49, wherein dopant ions of the waveguide core include Phosphorus and/or Fluorine and/or Aluminium and/or Boron and/or Germanium and/or Tin and/or Titanium and/or compounds of these elements.

51. A method as claimed in any of Claims 30 to 50, wherein the core layer includes Phosphorus oxide and/or Boron oxide.

52. A method as claimed in Claim 51, wherein the core layer comprises $P_2O_5-SiO_2$.

53. A method as claimed in any of Claims 30 to 52, wherein the refractive index of the waveguide core differs from that of the lower cladding layer by at least 0.05%.

54. A method as claimed in any of Claims 30 to 53, wherein the waveguide core includes silica and at least one Phosphorus oxide and wherein the silica to Phosphorus oxide ratio is in the range of 75 to 95 wt% silica to 5 to 25 wt% Phosphorus oxide.

55. A method as claimed in Claim 54, wherein the waveguide core has a silica to Phosphorus oxide ratio of 80 wt% silica to 20 wt% Phosphorus oxide.

56. A method as claimed in any of Claims 30 to 55, wherein the thickness of the waveguide core is in the range $2\mu m$ to $60\mu m$.

57. A method as claimed in Claim 56, wherein the thickness of the waveguide core is $6\mu m$.

58. A method as claimed in any of claims 31 to 57,

wherein said lower cladding layer and said buffer layer are formed substantially in the same step.

59. A method as claimed in any of claims 33 to 58, wherein the consolidation of the lower cladding layer is at a temperature or temperatures in the range 950°C to 1400°C.

60. A method as claimed in Claim 59, wherein the consolidation of the lower cladding layer is at a temperature or temperatures in the range 1100°C to 1350°C.

61. A method as claimed in any of Claims 33 to 60, wherein the consolidation of the core layer is at a temperature or temperatures in the range 950°C to 1400°C.

62. A method as claimed in Claim 61, wherein the consolidation of the core layer is at a temperature or temperatures in the range 1100°C to 1385°C.

63. A method as claimed in any of Claims 33 to 62, wherein the consolidation of the upper cladding layer is at a temperature or temperatures in the range 950°C to 1400°C.

64. A method as claimed in Claim 63, wherein the consolidation of the upper cladding layer is at a temperature or temperatures in the range 1100°C to 1350°C.

65. A method as claimed in any of Claims 33 to 64, wherein the temperature or temperature range at which the lower cladding layer is consolidated is greater than the temperature or temperature range at which the

core is consolidated.

66. A method as claimed in any of Claims 33 to 65, wherein the temperature or temperature range at which the upper cladding layer is consolidated is substantially equal to the temperature or temperature range at which the core layer is consolidated.

67. A method as claimed in any of Claims 33 to 67, wherein at least one of the lower cladding layer, the core layer, and the upper cladding layer is deposited by a Flame Hydrolysis Deposition process and/or Chemical Vapour Deposition process.

68. A method as claimed in Claim 67, wherein the Chemical Vapour Deposition process is a Low Pressure Chemical Vapour Deposition process or a Plasma Enhanced Chemical Vapour Deposition process.

69. A method as claimed in any of Claims 33 to 68, wherein the consolidation is by fusing using a Flame Hydrolysis Deposition burner.

70. A method as claimed in any of Claims 33 to 68, wherein the consolidation is by fusing in a furnace.

71. A method as claimed in either of Claims 69 or 70, wherein the step of fusing the lower cladding layer and the step of fusing the core layer are performed simultaneously.

72. A method as claimed in any of Claims 30 to 71, wherein the waveguide core formed from the core layer is square or rectangular in cross-section.

73. A method as claimed in any of Claims 30 to 72,

wherein the waveguide core is formed from the core layer using a dry etching technique and/or a photolithographic technique .and/or a mechanical sawing process.

74. A method as claimed in Claim 73, wherein the dry etching technique comprises a reactive ion etching process and/or a plasma etching process and/or an ion milling process.

75. A method as claimed in any of Claims 30 to 74, wherein the diffusion of the said mobile dopant ions from the waveguide core is isotropic.

76. A method as claimed in any of Claims 30 to 75, wherein the diffusion of the said mobile dopant ions from the waveguide core swells the boundary walls of the waveguide core.

77. A method as claimed in Claim 76, wherein the diffusion of the said mobile dopant ions swells the boundary walls of the waveguide core to form a substantially rounded waveguide core.

78. A method as claimed in Claim 77, wherein the rounded waveguide core is elliptical or circular in cross-section.

79. A waveguide substantially as described herein and with reference to Figs. 2A to 2E of the accompanying drawings.

80. A method of fabricating a waveguide substantially as described herein and with reference to Figs. 2A to 2E of the accompanying drawings.

ABSTRACT OF THE DISCLOSURE

A waveguide for an optical circuit comprises a substrate; a buffer layer formed on the substrate; a doped lower cladding layer formed on the buffer layer; a doped waveguide core formed on the lower cladding layer; and a doped upper cladding layer embedding the waveguide core. The waveguide core includes mobile dopant ions which have diffused into the upper cladding layer and the lower cladding layer to form an ion diffusion region around said waveguide core such that the waveguide core boundary walls are substantially smooth. Methods of fabricating the waveguide are also described. (Fig. 2E)

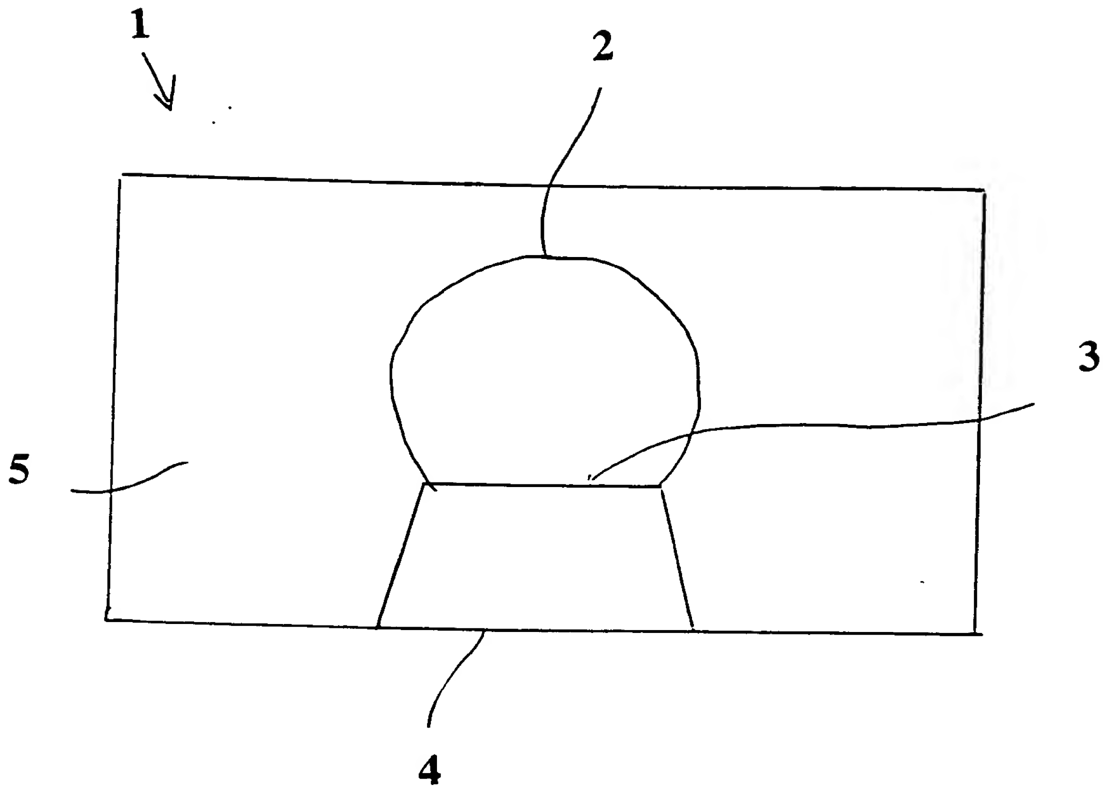

FIG. 1

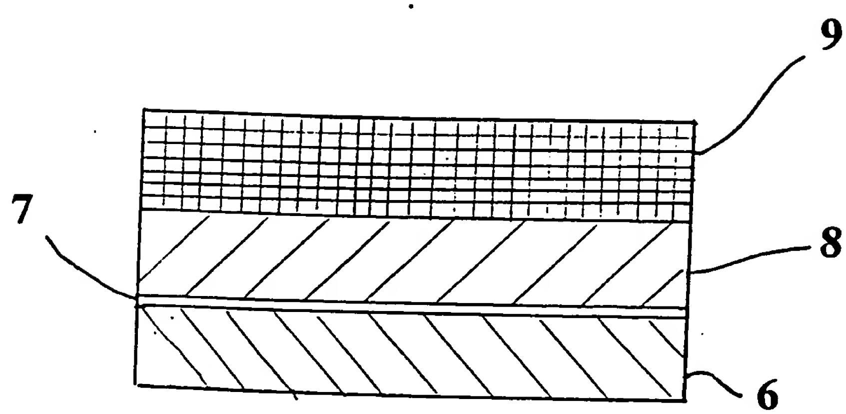

FIG. 2A

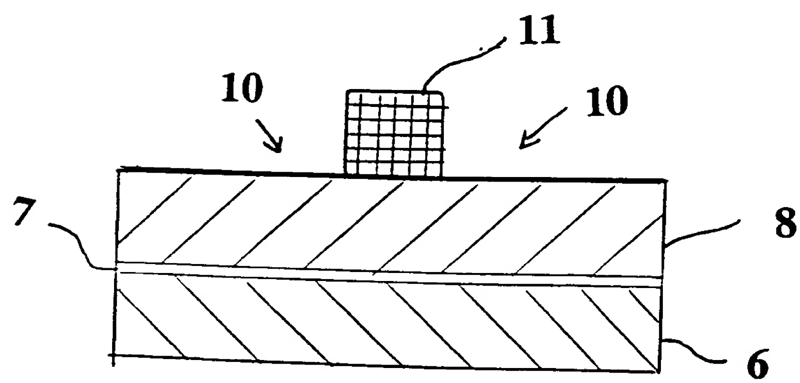

FIG. 2B

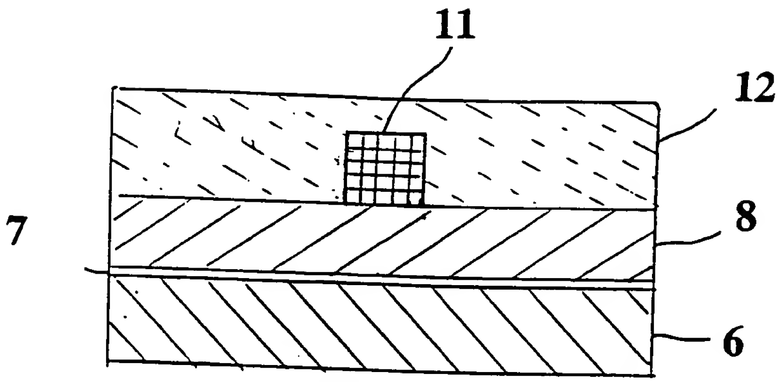

FIG. 2C

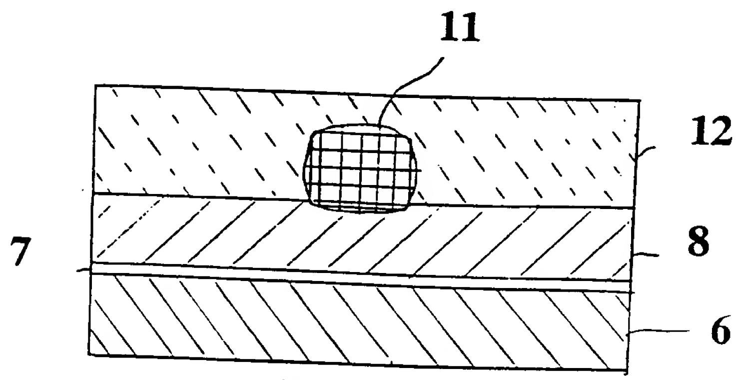

FIG. 2D

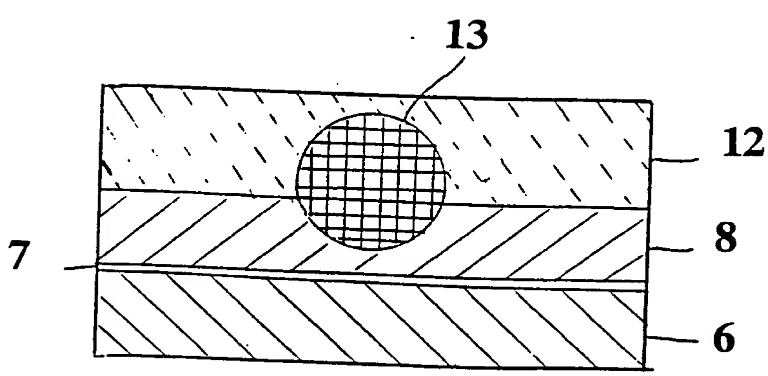

FIG. 2E

[illegible]

[illegible]

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